MULVANEY

Measurement of Flow of Water in Pipes by Means of Orifices

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MEASUREMENT OF FLOW OF WATER IN PIPES BY MEANS OF ORIFICES

BY

CHARLES STEWART MULVANEY

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This is to certify that the thesis prepared in the Department of Municipal and Sanitary Engineering by CHARLES STEWART MULVANEY entitled Measurement of Flow of Water in Pipes by Means of Orifices is approved by me as fulfilling this part of the requirements for the degree of Bachelor of Science in Civil Engineering.

V. R. Fleming
Instructor in Charge.

Approved:
W. Talbot
Professor of Municipal and Sanitary Engineering.

Approved:
Ira O. Baker.
Professor of Civil Engineering.

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I - INTRODUCTION

It is often desired to measure the flow of water in a pipe when none of the various methods generally used can be employed without involving a large expense. In many cases a flange joint can be opened and sprung apart enough to admit a thin orifice plate which, it is felt, might furnish a method, in such cases, for measuring water if the laws governing the flow were known. It is not expected that an orifice in a pipe line will prove to be an extremely sensitive or accurate method of measuring water, but rather it is hoped that it may afford a temporary means of measuring water with a reasonable degree of accuracy at times when other methods are not available.

The purpose of the experiments described in this thesis was to study the laws governing the flow through orifices in pipes with a view of deriving a general expression and reducing it to a workable basis.

In these experiments two sizes of pipe were used, 4-in. and 6-in. Six orifices varying in diameter were tested in the 4-in. pipe,and seven in the 6-in. pipe. The orifices used were made by turning circular openings in thin steel plates. The edges of the holes were sharp, not being beveled on the discharge side. The head lost was measured by means of a differential water gauge between any two sections.

II - THEORY AND AVAILABLE DATA

The principle of measuring the rate of flow of water in a pipe by means of an orifice in the pipe is somewhat similar to that of the Venturi meter. In the latter the loss of pressure head is in a large measure due to the difference of cross-sectional area of the pipe at two sections between which the lost head is measured. In other words, it is a change of the form of energy. In using orifices the loss of head is caused by the contraction of the stream on entering, and its expansion on leaving the orifice, or in this case it is an actual loss of energy.

An orifice in a pipe line might better be considered as a submerged orifice with a high velocity of approach and in this case the coefficient of discharge for the orifice used should be applied. If the same coefficient of discharge is used the theory for the Venturi meter and the theory of the submerged orifice are identical.

So far as is known by the writer there are no formulas by which the loss of head through an orifice in a pipe can be calculated. The formula usually employed for calculating the head lost due to an obstruction in a pipe cannot be expected to apply to this case because in that formula the loss is assumed to be due wholly to expansion. The loss due to contraction is small, yet it must be taken account of in reasonably accurate work.

In the theses of C. C. Rice and H. Polkowski tests are reported for the loss due to sudden expansion and sudden contraction, occurring separately. However, the results obtained by them cannot be used in connection with an orifice where the contraction and expansion occur successively, due to the fact that the cross-sectional area of stream going through the orifice is decreased materially before expanding.

It was found from the experiments referred to above, that the equation for the loss of head takes somewhat the same general form as the equation from Hoskins' Hydraulics which is:

$$H' = \left(\frac{F}{F'} - 1\right)^2 \frac{V^2}{2g}$$

In which: H' = loss of head in feet

$\frac{F}{F'}$ = ratio of larger area to smaller

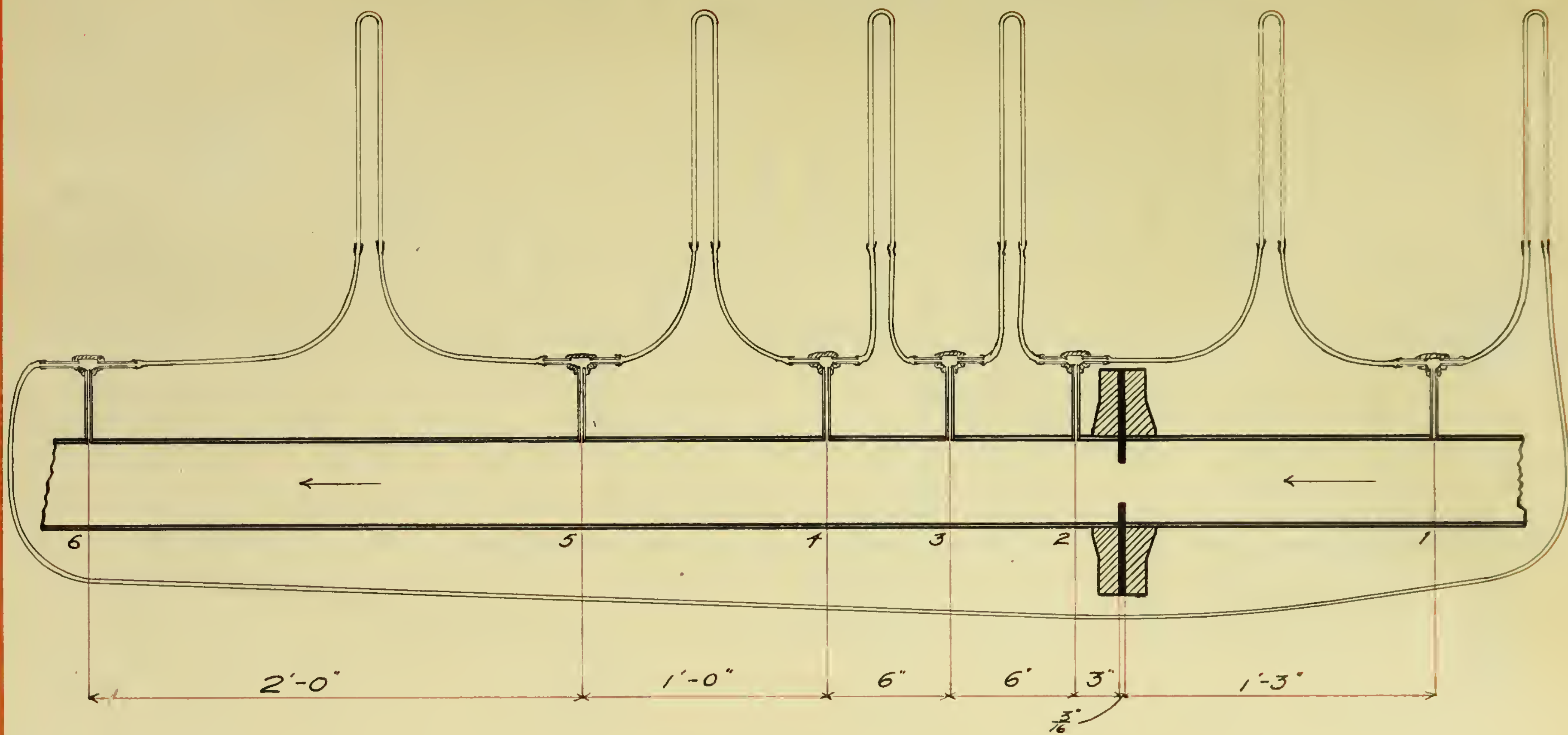
V = velocity in pipe in feet per second.

III - APPARATUS AND METHODS OF TESTING

As has been stated before the experiments were performed on 4-in. and 6-in. pipe. The line was made up of one 12 ft. and one 20 ft. length of 4-in. pipe, then two 15 ft. lengths of 6-in. pipe, and finally a short length of 3-in. pipe. Valves were placed at both ends of the line so that both the pressure and flow could be controlled as desired. By keeping the outlet valve partially closed it was certain that the pipe was flowing full of water.

The interior of the pipes was coated with rust and sediment to a slight extent as the pipes had all been in use for several years. No account was taken of this in figuring the cross-sectional areas.

The orifices were made in circular plates 3/16-in. thick. The openings were turned in a lathe to the required diameter. No attempt was made to polish any of the surfaces, but care was taken to see that the edges were sharp and that no burrs obstructed the orifices. Bolt holes were drilled through the plates to correspond to the holes in a standard 6-in. flange coupling. The plates were made in the above manner so they could be easily duplicated for further tests or for use in measuring water.



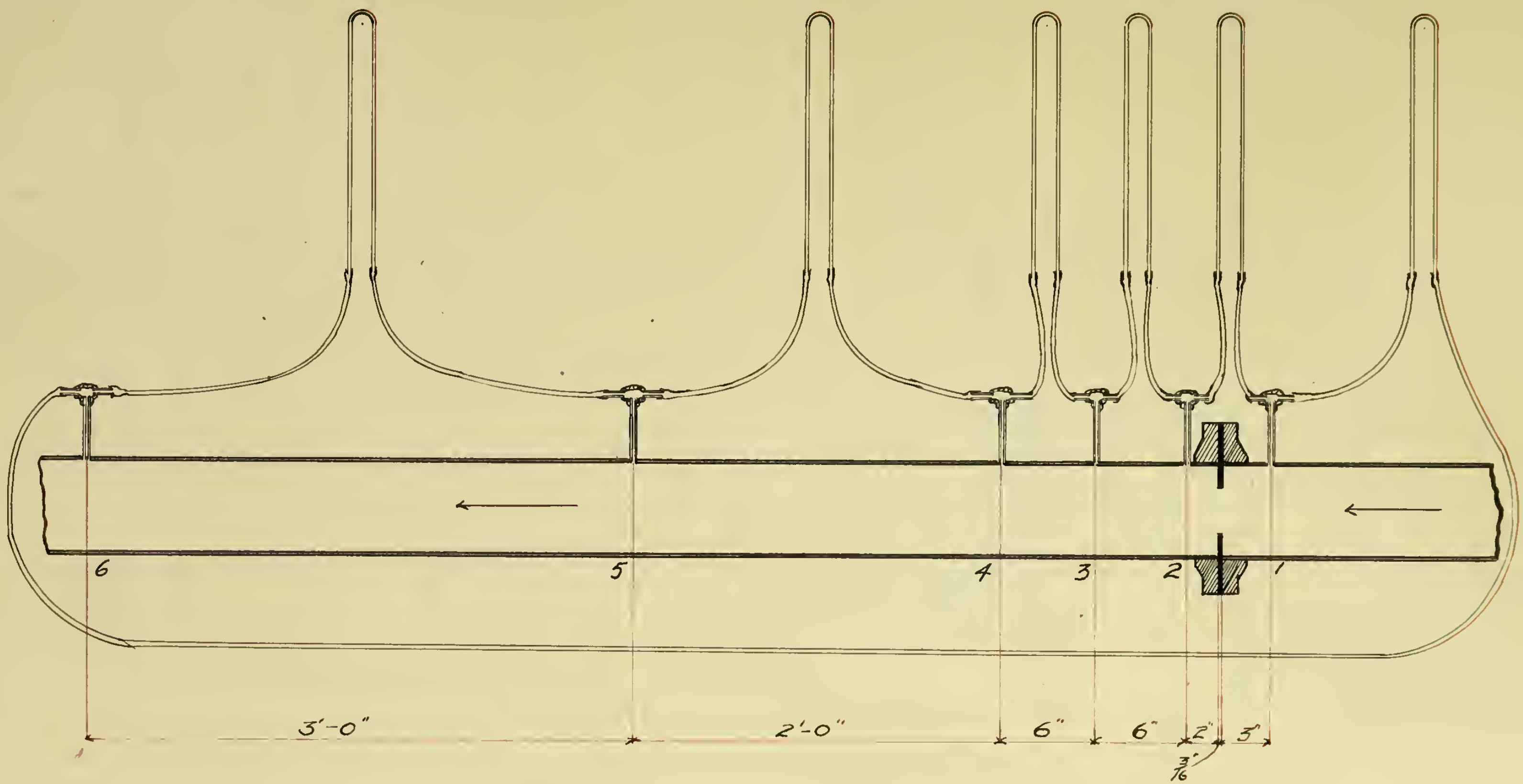
Distribution of Gauges on 4-in. Pipe.

Fig. 1

The diameters of the orifices tested were: 3/4-in., 1-in., 1 1/2-in., 2-in., 2 1/2-in., 3-in., 4-in. and 5-in. Tests were made on the first six in the 4-in. pipe and the last seven in the 6-in. pipe.

Holes for measuring pressure were drilled and tapped in the 4-in. pipe at intervals as shown in Figure 1. Piezometer tubes 1/4-inch in diameter were screwed into these holes and 1/4-in. tees screwed on the tubes. Care was taken that the tubes did not project into the pipe and in this manner cause errors in the pressures indicated. The ends of the tees were connected to inverted glass U-tubes by means of rubber hose. The differential gauge for measuring the change of pressure at sections immediately adjacent to the orifice, and the differential gauge for measuring the change of pressure between the extreme sections were made of glass tubes about 6 ft. long mounted on boards. Valves and drain-cocks were used on the bottom of the larger gauges to facilitate removing any air-pockets which might form in the pipe and tubes leading to the gauges. In all cases care was taken to see that no air-pockets formed in any of the connections of the gauges. Similar gauges were used on the 6-in. line as shown in Figure 2.

The water used was taken directly from the stand-pipe in the Hydraulics Laboratory which served to keep the head constant throughout any set of readings.



Distribution of Gauges on 6-in Pipe

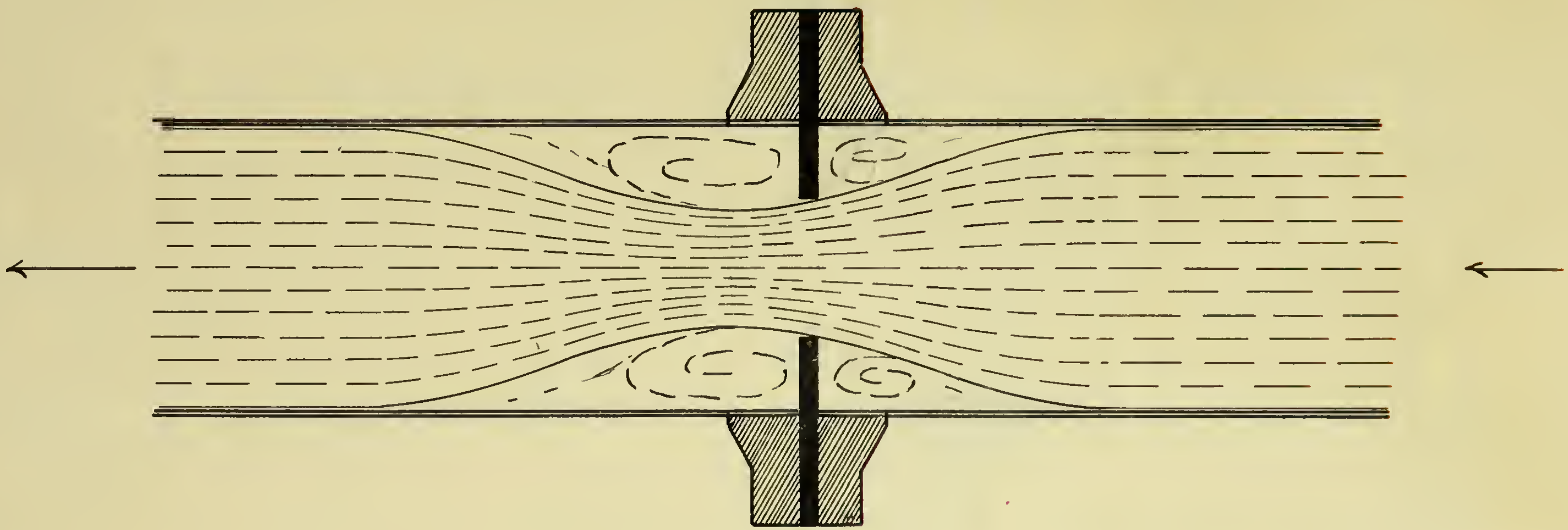
Fig. 2

In some cases difficulty was encountered in freeing the water from air.

The difference in height of water columns in the differential gauges was measured with a 4-ft. stick graduated to hundredths of a foot. The gauge connecting sections 1-6 and the gauge connecting sections 1-2, shown in Figures 1 and 2, were the only ones that could be read consistently. The other gauges either fluctuated too much to obtain a reading or registered a change which was too small to measure.

Measurements of the rate of flow on all orifices up to 3 inches in diameter in 4-in. pipe were made by taking the time required to discharge a given weight of water. The water was discharged directly into a tank on a pair of scales. The weights discharged varied from 50 to 500 pounds. The time was taken to the nearest half second by means of a stop-watch.

On the 3-in. orifice in the 4-in. pipe and all the orifices in 6-in. pipe the rate of flow was obtained by a Venturi meter. The meter was calibrated with a pair of scales and its discharge curve drawn. The head on the Venturi meter was read on a scale graduated to 0.01 ft. the nearest 0.1 division being estimated, and the discharge corresponding to this head was taken directly from the discharge curve. Discharges ranging from .05 to .5 cu. ft. per sec. could be measured accurately in this manner.



Longitudinal Section of Stream

Fig. 3

IV - EXPERIMENTAL DATA AND DISCUSSION

In this work only the differential gauge readings on sections 1-6, Figures 1 and 2, were considered, because this gauge gave more consistent readings than the one on sections 1-2. When the stream passed section 2, as shown in Figure 3, the flow was not uniform over the entire section of the pipe.

The head lost between the sections 1 and 2 (Figures 1 and 2) was always larger than the total loss between 1 and 6. This difference increased as the rate of flow increased. There was an increase in the pressure head between the sections 2 and 3, and 3 and 4. The reason for this [illegible] ~~being~~ that the velocity head was large close to the orifice and diminished farther away. The water columns in the latter two gauges fluctuated continually and consequently no satisfactory readings on them could be taken. The losses between sections 4 and 5, and 5 and 6 were negligible in all cases.

The values of head lost in feet from section 1 to section 6 were plotted as abscisas, and the values of the discharge in cu. ft. per sec. were plotted as ordinates on logarithmic coordinate paper. These were plotted for all the orifices and with the exception of the 1-in. and 5-in. orifices in 6-in. pipe. These head-discharge curves proved to be straight lines, as shown in black on Plates I and II. The reason that the other two head-discharge

curves were not straight was probably due to the presence of air in the water columns of the gauge on the Venturi meter.

In the following discussion the notations used will be:

q = rate of discharge in cu. ft. per sec.

h = head lost in feet between 1-6.

C_1 = ordinate of the point of intersection of any head-discharge curve with the line, log $h = 0$, or where $h = 1$.

m = the tangent of the angle any head-discharge curve makes with axis of ordinates.

F_o = area of the orifice in sq. ft.

F_p = cross-sectional area of the pipe in sq. ft.

The straight line equation of the form:

$$y = mx + b$$

In which, y equals the ordinate of any point, x the abscisa, m the slope of the line, and b is the ordinate of the point of intersection of the line with the y axis; was used to obtain the equations of the head-discharge curves. The result was:

$$\log q = m \log h + \log c_1$$

Reducing the above equation from the logarithmic form we obtain the relation:

$$q = c_1 h^m$$

The values of c_1 and m were taken directly from the curves and are recorded in Table I, page 15.

It was found that by plotting on logarithmic paper the values of c_1 for the 4-in. pipe against the ratio of the cross-sectional area of the pipe to the area of the orifice, minus 1, $\left(\frac{F_p}{F_o}-1\right)$, that the resulting lines were straight. Plate III. This was also true for the 6-in. pipe. The equation for these lines taking the form:

$$\log c_1 = n \log\left(\frac{F_p}{F_o}-1\right) + \log c_2$$

Where the log c_2 was the q intercept at the point where $\left(\frac{F_p}{F_o}-1\right)$ equaled 1, and n equaled the slope of the lines. Reducing the above equation we have:

$$c_1 = c_2\left(\frac{F_p}{F_o}-1\right)^n$$

The values of n and c_2 were taken directly from the lines and tabulated in Table I, page 15.

Substituting this value for c_1 in the equation for the rate of flow the result is:

$$q = c_2\left(\frac{F_p}{F_o}-1\right)^n h^m$$

Furthermore, from the curves on Plate III the values of c_2 obtained were approximately proportional to the square of the diameter of the pipe. That is:

$$c_2 = c_3 d^2$$

where $$c_3 = \frac{c_2}{d^2}$$

In which d is the diameter of the pipe in feet. This may be expressed in terms of the cross-sectional area

of the pipe as follows:

$$F_p = \frac{1}{4}\pi d^2$$

$$d^2 = \frac{4}{\pi} F_p$$

$$c_2 = c_3 \frac{4}{\pi} F_p = c_4 F_p$$

The final equation for obtaining the rate of flow for any of the orifices tested in 4-in. and 6-in. pipe is:

$$q = c_4 F_p \left(\frac{F_p}{F_o} - 1\right)^n h^m \qquad (1)$$

The values of all the quantities on the right hand side of equation (1) being given in Table I, page 15. The equations given in the next to the last column of Table I agree fairly closely with the experiments. However, these equations are too cumbersome and complicated for general use.

In order to obtain a set of equations which would be reasonably accurate and simple, the exponent n was assumed to be -1.0 and m to be 0.5. Both being so close to these values that these assumptions could be made without a large error entering in the work. From this, the principal equation took the form:

$$q = c_4 F_p \left(\frac{F_p}{F_o} - 1\right)^{-1.0} \sqrt{h}$$

From which

$$q = c_4 \left(\frac{F_p F_o}{F_p - F_o}\right) \sqrt{h}$$

or

$$q = c_5 \left(\frac{F_p F_o}{F_p - F_o}\right) \sqrt{2gh} \qquad (2)$$

Using equation 2 and several values of q for each orifice an average C_5 was found for each line. These values are given in the last column of Table I.

In performing these experiments it was found that the small orifices did not allow a very large

range of discharge, and the large orifices did not allow much range in the head lost within the limits of the tests. The orifices in which $\frac{F_p}{F_o}$ varied between 4 and 17 gave good variations of both discharge and head lost. The following general equation gives fairly approximate results for the above mentioned range of sizes of orifices throughout the range of the experiments.

$$q = .565 \frac{F_o F_p}{F_p - F_o} \sqrt{2gh} \qquad (3)$$

The discharge curves for this equation are plotted in red on plates I and II. This is the equation obtained by the usual formula for loss of head due to sudden expansion in which a coefficient of discharge of .565 has to be applied.

The readings between 1 and 2 were plotted similarly to those of 1 and 6, and these curves were also straight lines. Owing to the lack of time no attempt was made to deduce equations for these discharge curves.. (Plates IV and V.)

TABLE I

Diam. 4-in. pipe = 4.10-in.
Diam 6-in. pipe = 6.10-in.

Size of Pipe	Size of Orifice	Actual Diam. of Orifice	m	c_1	$\frac{F_p}{F_o}$	$\frac{F_p}{F_o}-1$	c_2	n	c_4	Equation	c_5
4-in.	$\frac{3}{4}$-in.	0.75-in.	.506	.015	29.90	28.90	.388	-.967	4.45	$q = 4.45\, F_p\left(\frac{F_p}{F_o}-1\right)^{-.967} h^{.506}$	.590
4-in.	1-in.	1.00-in.	.508	.027	16.81	15.81	.388	-.967	4.45	$q = 4.45\, F_p\left(\frac{F_p}{F_o}-1\right)^{-.967} h^{.508}$	.575
4-in.	$1\frac{1}{2}$-in.	1.48-in.	.483	.065	7.68	6.68	.388	-.967	4.45	$q = 4.45\, F_p\left(\frac{F_p}{F_o}-1\right)^{-.967} h^{.483}$	.565
4-in.	2-in.	2.00-in.	.501	.124	4.21	3.21	.388	-.967	4.45	$q = 4.45\, F_p\left(\frac{F_p}{F_o}-1\right)^{-.967} h^{.501}$	.530
4-in.	$2\frac{1}{2}$-in.	2.49-in.	.517	.230	2.71	1.71	.388	-.967	4.45	$q = 4.45\, F_p\left(\frac{F_p}{F_o}-1\right)^{-.967} h^{.517}$	.500
4-in.	3-in.	3.01-in.	.511	.421	1.86	0.86	.388	-.967	4.45	$q = 4.45\, F_p\left(\frac{F_p}{F_o}-1\right)^{-.967} h^{.511}$	.470
6-in.	1-in.				Curves	not		satisfactory			
6-in.	$1\frac{1}{2}$-in.	1.48-in.	.472	.062	17.00	16.00	.830	-.939	4.22	$q = 4.22\, F_p\left(\frac{F_p}{F_o}-1\right)^{-.939} h^{.472}$	.590
6-in.	2-in.	2.00-in.	.498	.110	9.32	8.32	.830	-.939	4.22	$q = 4.22\, F_p\left(\frac{F_p}{F_o}-1\right)^{-.939} h^{.498}$	.565
6-in.	$2\frac{1}{2}$-in.	2.49-in.	.498	.185	6.01	5.01	.830	-.939	4.22	$q = 4.22\, F_p\left(\frac{F_p}{F_o}-1\right)^{-.939} h^{.498}$	.559
6-in.	3-in.	3.01-in.	.492	.287	4.11	3.11	.830	-.939	4.22	$q = 4.22\, F_p\left(\frac{F_p}{F_o}-1\right)^{-.939} h^{.492}$	.548
6-in.	4-in.	4.02-in.	.453	.595	2.30	1.30	.830	-.939	4.22	$q = 4.22\, F_p\left(\frac{F_p}{F_o}-1\right)^{-.939} h^{.453}$	.500
6-in.	5-in.				Curves	not		satisfactory			

V - CONCLUSIONS

To obtain the largest range of both discharge and head lost the orifices in which $\frac{F_p}{F_o}$ varies from 4 to 17 give the best results.

Using equation 3 on orifices as mentioned above, q can be determined in all cases within 5 per cent of the actual value.

By transforming equation 3 to get an expression for the head lost in the apparatus we have:

$$h = 3.14 \left(\frac{F_p}{F_o} - 1\right)^2 \frac{V_p^2}{2g}$$

In which V_p equals the velocity in the pipe in ft. per sec. Taking the extreme ranges of $\frac{F_p}{F_o}$ as 4 and 17 the lost head will vary from 28 to 800 velocity heads in the pipe. These losses are so high that it would not be economical to use this method for measuring water except for temporary and emergency cases.

It would have been interesting to have had these orifices calibrated as submerged orifices, and to have comparedthe equation of flow found in this manner with that obtained by these experiments. Also knowing the coefficients of the submerged orifices a simpler and more exact expression might be derived for a rate of flow through an orifice in a pipe in terms of these coefficients.

As the cross-sectional area of the stream passing through the orifice is smaller than the area of the

orifice an error is introduced by using the area of the orifice in the equations. From these experiments it appears that the coefficient $\underline{C_5}$ in equation 2 decreases as the ratio $\frac{F_p}{F_o}$ decreases. The writer was unable to obtain any satisfactory relation between these two quantities. For that reason no general equation could be written for any orifice in any of the pipes tested.

Because of its simplicity and cheapness the method of measuring flow of water in a pipe by means of orifices is likely to be of value if properly studied and expanded to larger sizes of pipes.

3/4 in. ORIFICE IN 4-in. PIPE

No.	Discharge pounds	Time seconds	Rate of Discharge cu. Ft. per sec.	Velocity in Orifice ft. per sec.	Head Lost 1-2 feet	Head Lost 1-6 feet
1	100	61.0	.0262	8.53	3.16	3.05
2	100	60.6	.0264	8.60	3.07	2.96
3	100	62.0	.0258	8.40	2.93	2.83
4	100	61.0	.0262	8.53	2.99	2.89
5	100	68.4	.0234	7.62	2.49	2.40
6	100	74.9	.0214	6.97	2.06	2.01
7	100	76.0	.0211	6.86	2.01	1.97
8	100	77.0	.0208	6.77	1.96	1.91
9	100	80.2	.0200	6.52	1.79	1.67
10	100	85.4	.0188	6.12	1.57	1.51
11	100	97.0	.0165	5.38	1.23	1.20
12	100	96.0	.0167	5.43	1.25	1.23
13	100	107.5	.0149	4.84	1.00	0.97
14	100	128.0	.0125	4.07	0.71	0.70
15	100	140.0	.0114	3.71	0.60	0.58
16	100	251.0	.0064	2.08	0.20	0.20
17	50	164.0	.0049	1.60	0.11	0.12
18	100	60.0	.0267	8.37	3.52	3.43
19	100	54.0	.0294	9.58	3.84	3.70
20	100	58.0	.0276	9.00	3.43	3.30
21	100	61.0	.0262	8.53	3.20	3.05
22	100	69.0	.0232	7.55	2.46	2.36
23	100	82.0	.0195	6.35	1.69	1.62
24	100	98.0	.0163	5.31	1.18	1.15
25	50	62.0	.0129	4.20	0.74	0.70

1-in. ORIFICE IN 4-in. PIPE

No.	Discharge pounds	Time seconds	Rate of Discharge cu. ft. per sec.	Velocity in Orifice ft. per sec.	Head Lost 1-2 feet	Head Lost 1-6 feet
1	50	145.0	.0055	1.01	0.04	0.04
2	50	100.0	.0080	1.47	0.11	0.10
3	50	59.0	.0135	2.48	0.26	0.25
4	100	91.0	.0176	3.24	0.45	0.43
5	100	76.0	.0210	3.86	0.68	0.62
6	100	66.0	.0242	4.64	0.88	0.81
7	100	60.0	.0267	4.91	1.03	0.95
8	100	55.0	.0291	5.35	1.21	1.13
9	150	78.0	.0308	5.67	1.34	1.25
10	150	70.0	.0343	6.31	1.71	1.60
11	150	66.0	.0364	6.70	1.90	1.79
12	150	62.5	.0384	7.07	2.10	1.97
13	150	58.0	.0414	7.61	2.42	2.25
14	150	57.0	.0421	7.75	2.58	2.40
15	200	73.0	.0438	8.05	2.90	2.69
16	200	68.0	.0471	8.68	3.28	3.03
17	200	64.0	.0500	9.20	3.72	3.44
18	200	60.0	.0534	9.81	4.12	3.80
19	200	66.0	.0485	8.92	3.57	3.30
20	200	68.0	.0471	8.67	3.27	3.04
21	150	54.0	.0445	8.20	2.89	2.68
22	150	69.0	.0348	6.40	1.75	1.61
23	100	58.0	.0276	5.08	1.10	1.04

1 1/2 in. ORIFICE IN 4-in. PIPE

No.	Discharge pounds	Time seconds	Rate of Discharge cu. ft. per sec.	Velocity in Orifice ft. per sec.	Head Lost 1-2 feet	Head Lost 1-6 feet
1	300	41.0	.1160	9.46	4.10	3.43
2	300	41.0	.1160	9.46	3.90	3.30
3	300	41.6	.1154	9.41	3.74	3.16
4	300	43.0	.1117	9.10	3.51	2.99
5	300	45.0	.1067	8.69	3.23	2.75
6	300	46.5	.1030	8.40	3.05	2.60
7	300	48.0	.1000	8.16	2.82	2.40
8	300	50.5	.0952	7.76	2.50	2.15
9	300	54.0	.0889	7.24	2.25	1.90
10	300	57.0	.0843	6.87	1.97	1.67
11	300	57.0	.0843	6.87	1.97	1.67
12	300	60.0	.0800	6.52	1.71	1.44
13	300	64.0	.0750	6.11	1.57	1.34
14	300	70.0	.0685	5.58	1.30	1.10
15	250	64.0	.0625	5.09	1.07	0.92
16	200	56.0	.0572	4.66	0.90	0.77
17	200	67.0	.0516	4.21	0.63	0.55
18	150	45.0	.0534	4.35	0.80	0.67
19	100	50.0	.0320	2.61	0.27	0.23
20	200	43.0	.0745	6.07	1.55	1.30
21	300	53.0	.0905	7.38	2.37	1.97
22	300	46.0	.1042	8.58	3.08	2.60
23	500	71.0	.1127	9.18	4.05	3.40

2-in. ORIFICE IN 4-in. PIPE

No.	Discharge pounds	Time seconds	Rate of Discharge cu. ft. per sec.	Velocity in Orifice ft. per sec.	Head Lost 1-2 feet	Head Lost 1-6 feet
1	200	14.5	.2205	10.11	4.39	3.20
2	200	15.0	.2133	9.78	4.15	3.15
3	200	15.5	.2065	9.48	3.84	2.85
4	200	16.0	.2000	9.18	3.50	2.58
5	200	16.8	.1905	8.74	3.30	2.42
6	200	17.6	.1820	8.35	2.98	2.20
7	200	18.2	.1760	8.07	2.84	2.10
8	300	27.0	.1775	8.14	2.67	1.98
9	300	28.7	.1670	7.66	2.38	1.75
10	300	29.6	.1620	7.44	2.20	1.60
11	300	32.0	.1500	6.89	1.89	1.38
12	300	35.0	.1370	6.33	1.63	1.20
13	300	38.0	.1263	5.80	1.40	1.02
14	300	38.5	.1247	5.71	1.35	1.00
15	300	44.0	.1090	5.00	1.01	0.75
16	300	43.0	.1116	5.12	1.06	0.80
17	300	49.0	.0980	4.50	0.80	0.59
18	300	61.0	.0787	3.61	0.52	0.40
19	200	63.0	.0508	2.33	0.20	0.17
20	100	55.0	.0291	1.33	0.08	0.05
21	300	44.0	.1090	5.00	1.03	0.75
22	300	32.0	.1500	6.88	1.90	1.40
23	300	27.0	.1780	8.16	2.70	2.00
24	300	24.0	.2000	9.18	3.65	2.70
25	300	20.0	.2400	11.00	4.69	3.41

2 1/2-in. ORIFICE IN 4-in. PIPE

No.	Discharge pounds	Time seconds	Rate of Discharge cu. ft. per sec.	Velocity in Orifice ft. per sec.	Head Lost 1-2 feet	Head Lost 1-6 feet
1	100	26.0	.0615	1.80	0.11	0.08
2	200	32.0	.1000	2.94	0.30	0.20
3	200	26.0	.1230	3.61	0.44	0.30
4	200	24.0	.1330	3.90	0.57	0.37
5	300	32.0	.1500	4.40	0.67	0.43
6	300	29.5	.1625	4.77	0.81	0.51
7	300	27.0	.1780	5.22	0.92	0.57
8	300	23.0	.2082	6.12	1.28	0.80
9	300	20.5	.2340	6.86	1.60	1.01
10	200	13.0	.2460	7.22	1.92	1.20
11	200	12.4	.2580	7.56	2.20	1.40

continues on next page

2 1/2 in. ORIFICE IN 4-in. PIPE (continued)

No.	Head on Venturi Meter Feet.	Rate of Discharge cu. ft. per sec.	Velocity in Orifice ft. per sec.	Head Lost 1-2 feet	Head Lost 1-6 feet
12	0.910	.217	6.36	1.40	0.86
13	1.230	.253	7.59	1.89	1.20
14	1.545	.283	8.36	2.32	1.46
15	1.670	.245	8.83	2.52	1.60
16	1.860	.311	9.30	2.90	1.80
17	2.130	.334	9.94	3.26	2.05
18	2.410	.358	10.55	3.75	2.35
19	2.770	.382	11.29	4.02	2.67
20	3.070	.405	11.88	4.47	2.97
21	0.390	.139	4.08	0.52	0.34
22	0.450	.150	4.66	0.68	0.43
23	0.480	.155	4.78	0.72	0.45

3-in. ORIFICE IN 4-in. PIPE

No.	Head on Venturi Meter Feet.	Rate of Discharge cu. ft. per sec.	Velocity in Orifice ft. per sec.	Head Lost 1-2 feet	Head Lost 1-6 feet
1	0.20	.0995	2.00	0.10	0.05
2	0.38	.137	2.79	0.18	0.10
3	0.44	.149	3.03	0.22	0.14
4	0.76	.196	3.98	0.38	0.21
5	1.11	.242	4.89	0.56	0.32
6	1.33	.262	5.33	0.69	0.39
7	1.68	.296	6.03	0.85	0.50
8	1.96	.320	6.51	1.00	0.57
9	2.26	.345	7.01	1.17	0.68
10	2.46	.360	7.32	1.30	0.74
11	2.71	.380	7.73	1.41	0.80
12	2.98	.397	8.08	1.57	0.89
13	3.26	.417	8.49	1.69	0.95
14	3.39	.425	8.65	1.77	1.00
15	3.80	.451	9.18	1.97	1.10
16	3.96	.460	9.36	2.11	1.20
17	4.04	.465	9.46	2.25	1.28
18	0.15	.0860	1.75	0.08	0.04
19	0.75	.195	3.97	0.39	0.22
20	1.55	.283	5.76	0.79	0.45
21	2.14	.335	6.82	1.08	0.62
22	2.70	.379	7.71	1.39	0.80
23	3.15	.410	8.34	1.64	0.94
24	3.40	.428	8.71	1.77	1.00
25	3.64	.441	8.98	1.88	1.08

1-in. ORIFICE IN 6-in. PIPE

No.	Head on Venturi Meter Feet.	Rate of Discharge Cu. Ft. per sec.	Velocity in Orifice ft. per sec.	Head Lost 1-2 feet	Head Lost 1-6 feet
1	0.010	.0220	4.05	0.17	0.15
2	0.015	.0272	5.00	0.54	0.50
3	0.020	.0314	5.78	0.86	0.83
4	0.025	.0351	6.46	1.36	1.32
5	0.040	.0444	8.16	2.76	2.69
6	0.055	.0520	9.57	3.83	3.72
7	0.060	.0544	10.00	4.02	3.90
8	0.050	.0496	9.15	3.43	3.32
9	0.035	.0415	7.64	2.34	2.26
10	0.021	.0322	5.93	1.47	1.42
11	0.015	.0272	5.00	0.97	0.92
12	0.010	.0220	4.05	0.45	0.41

1 1/2-in. ORIFICE IN 6-in. PIPE

No.	Head on Venturi Meter Feet.	Rate on Discharge cu. ft. per sec.	Velocity in Orifice ft. per sec.	Head Lost 1-2 feet	Head Lost 1-6 feet
1	0.021	.0321	2.62	0.25	0.22
2	0.037	.0427	3.48	0.50	0.45
3	0.045	.0471	3.93	0.59	0.55
4	0.060	.0544	4.43	0.79	0.74
5	0.063	.0557	4.54	0.85	0.77
6	0.079	.0624	5.08	1.10	1.03
7	0.087	.0655	5.34	1.22	1.14
8	0.098	.0695	5.66	1.38	1.29
9	0.106	.0720	5.86	1.50	1.38
10	0.119	.0762	6.20	1.66	1.53
11	0.148	.0855	6.96	2.10	1.91
12	0.173	.0925	7.55	2.50	2.32
13	0.210	.1020	8.31	3.05	2.83
14	0.248	.1100	8.97	3.57	3.33
15	0.260	.1130	9.21	3.80	3.54
16	0.270	.1160	9.46	3.94	3.68
17	0.235	.1070	8.73	3.45	3.22
18	0.187	.0973	7.93	2.70	2.50
19	0.271	.1160	9.46	4.00	3.72
20	0.207	.1010	8.24	2.98	2.78
21	0.171	.0920	7.50	2.49	2.31
22	0.117	.0755	6.16	1.65	1.53
23	0.086	.0651	5.31	1.19	1.10
24	0.045	.0471	3.84	0.59	0.55
25	0.016	.0281	2.29	0.19	0.18

2-in. ORIFICE IN 6-in. PIPE

No.	Head on Venturi Meter feet.	Rate of Discharge cu. ft. per sec.	Velocity in Orifice ft. per sec.	Head Lost 1-2 feet	Head Lost 1-6 feet
1	0.830	.2060	9.45	3.90	3.40
2	0.828	.2050	9.41	3.85	3.39
3	0.793	.2010	9.22	3.70	3.26
4	0.780	.1990	9.13	3.54	3.13
5	0.695	.1870	8.58	3.20	2.82
6	0.618	.1770	8.12	2.90	2.56
7	0.550	.1660	7.61	2.55	2.25
8	0.491	.1570	7.20	2.25	1.98
9	0.419	.1430	6.56	1.91	1.70
10	0.365	.1330	6.10	1.69	1.50
11	0.312	.1250	5.73	1.41	1.25
12	0.266	.1140	5.23	1.19	1.05
13	0.200	.0995	4.56	0.86	0.77
14	0.142	.0835	3.83	0.61	0.54
15	0.110	.0734	3.36	0.49	0.44
16	0.067	.0574	2.63	0.29	0.26
17	0.043	.0460	2.11	0.16	0.14
18	0.079	.0624	2.86	0.33	0.29
19	0.135	.0813	3.73	0.60	0.53
20	0.205	.1010	4.64	0.92	0.84
21	0.270	.1160	5.33	1.21	1.08
22	0.408	.1430	6.56	1.87	1.65
23	0.691	.1870	8.58	3.21	2.80
24	0.753	.1960	9.00	3.52	3.10
25	0.498	.1580	7.25	2.52	2.20

2 1/2-in. ORIFICE IN 6-in. PIPE

No.	Head on Venturi Meter feet.	Rate of Discharge cu. ft. per sec.	Velocity in Orifice ft. per sec.	Head Lost 1-2 feet	Head Lost 1-6 feet
1	1.960	.321	9.42	3.67	3.00
2	1.815	.318	9.33	3.39	2.79
3	1.698	.299	8.77	3.18	2.60
4	1.469	.277	8.12	2.74	2.25
5	1.416	.271	7.95	2.64	2.16
6	1.150	.244	7.15	2.12	1.75
7	0.967	.222	6.51	1.79	1.46
8	0.590	.173	5.07	1.08	0.89
9	0.451	.151	4.43	0.81	0.69
10	0.343	.131	3.83	0.62	0.51
11	0.249	.111	3.26	0.37	0.44
12	0.192	.0975	2.86	0.31	0.25
13	0.141	.083	2.43	0.23	0.19
14	0.090	.067	1.95	0.14	0.11
15	0.535	.164	4.71	0.95	0.80
16	0.644	.181	5.31	1.16	0.98
17	0.810	.203	5.95	1.50	1.24
18	0.700	.188	5.51	1.30	1.07
19	1.140	.243	7.13	2.10	1.74
20	1.340	.265	7.77	2.49	2.05
21	1.532	.283	8.30	2.88	2.35
22	1.701	.299	8.76	3.19	2.62
23	1.865	.312	9.15	3.56	2.91
24	1.984	.323	9.47	3.70	3.04
25	0.955	.221	6.48	1.75	1.44

3-in. ORIFICE IN 6-in. PIPE

No.	Head on Venturi Meter Feet.	Rate of Discharge cu. ft. per sec.	Velocity in Orifice ft. per sec.	Head Lost 1-2 feet	Head Lost 1-6 feet
1	3.360	.422	8.60	3.00	2.26
2	3.265	.418	8.50	2.85	2.14
3	3.160	.410	8.34	2.75	2.05
4	3.060	.405	8.25	2.68	2.00
5	2.970	.396	8.05	2.60	1.92
6	2.813	.388	7.90	2.42	1.82
7	2.730	.381	7.75	2.35	1.75
8	2.490	.364	7.40	2.15	1.60
9	2.309	.350	7.12	2.00	1.53
10	2.127	.333	6.77	1.84	1.40
11	1.845	.311	6.33	1.59	1.18
12	1.665	.294	5.98	1.42	1.05
13	1.577	.287	5.84	1.35	1.00
14	1.170	.247	5.03	1.00	0.74
15	0.680	.186	3.78	0.57	0.42
16	0.465	.153	3.11	0.39	0.27
17	0.280	.118	2.40	0.24	0.18
18	0.125	.078	1.60	0.10	0.06
19	0.598	.174	3.54	0.50	0.37
20	0.810	.203	4.13	0.69	0.50
21	1.165	.247	5.03	1.00	0.75
22	1.698	.299	6.08	1.45	1.09
23	2.215	.341	6.94	1.88	1.43
24	2.812	.387	7.87	2.42	1.82
25	3.410	.427	8.69	3.02	2.26

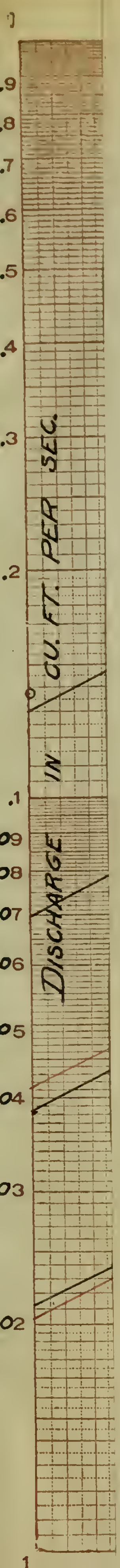
4-in. ORIFICE IN 6-in. PIPE

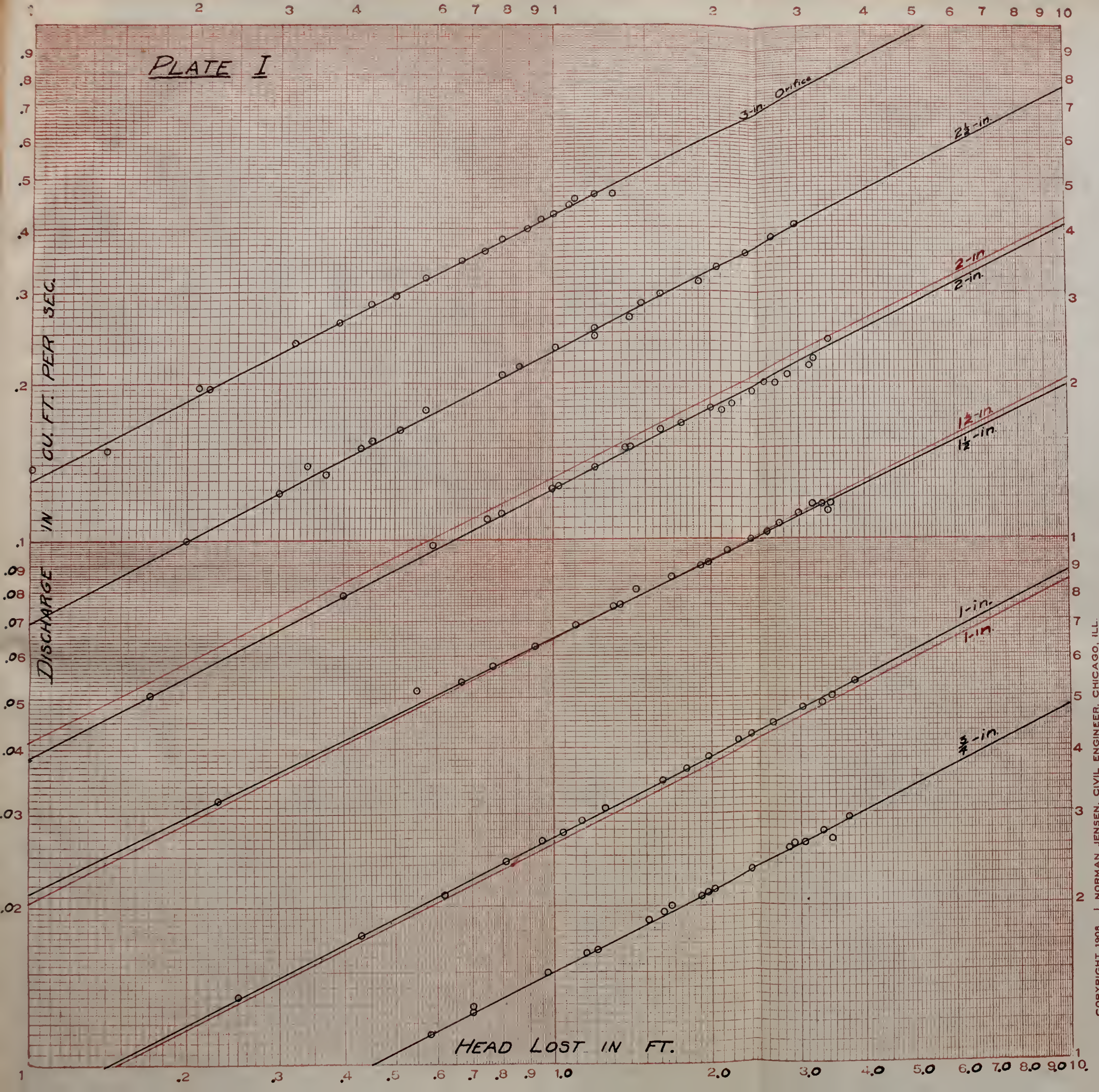
No.	Head on Venturi Meter feet.	Rate of Discharge cu. ft. per sec.	Velocity in Orifice ft. per sec.	Head Lost 1-2 feet	Head Lost 1-6 feet
1	0.265	.114	1.31	0.05	0.03
2	0.452	.151	1.73	0.10	0.06
3	0.635	.180	2.06	0.15	0.08
4	0.960	.220	2.55	0.21	0.12
5	1.465	.276	3.16	0.31	0.17
6	1.826	.309	3.54	0.40	0.23
7	2.080	.330	3.78	0.46	0.28
8	2.500	.363	4.16	0.53	0.35
9	2.780	.384	4.40	0.61	0.38
10	3.105	.409	4.79	0.68	0.41
11	3.420	.428	4.90	0.77	0.48
12	3.680	.443	5.07	0.81	0.50
13	3.820	.451	5.17	0.89	0.55
14	3.900	.458	5.24	0.97	0.60

5-in. ORIFICE IN 6-in. PIPE

No.	Head on Venturi Meter feet.	Rate of Discharge cu. ft. per sec.	Velocity in Orifice ft. per sec.	Head Lost 1-2 feet	Head Lost 1-6 feet
1	0.727	.193	1.42	0.04	0.02
2	0.930	.219	1.61	0.06	0.03
3	1.415	.271	1.99	0.07	0.04
4	1.770	.303	2.23	0.10	0.05
5	2.040	.328	2.41	0.12	0.06
6	2.250	.345	2.54	0.13	0.07
7	2.480	.362	2.66	0.14	0.09
8	2.725	.381	2.80	0.17	0.10
9	3.140	.410	3.01	0.18	0.10
10	3.480	.431	3.17	0.21	0.11
11	3.710	.448	3.30	0.24	0.13
12	3.940	.460	3.38	0.26	0.14
13	4.170	.472	3.47	0.28	0.15

PLATE I



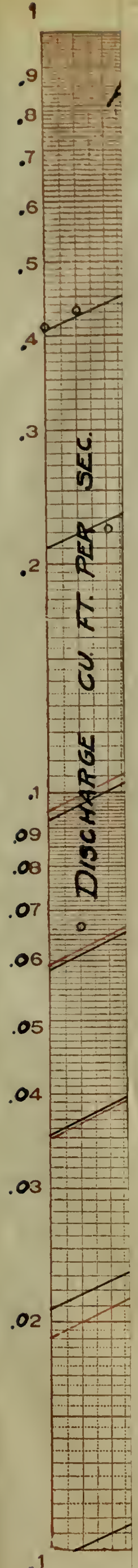


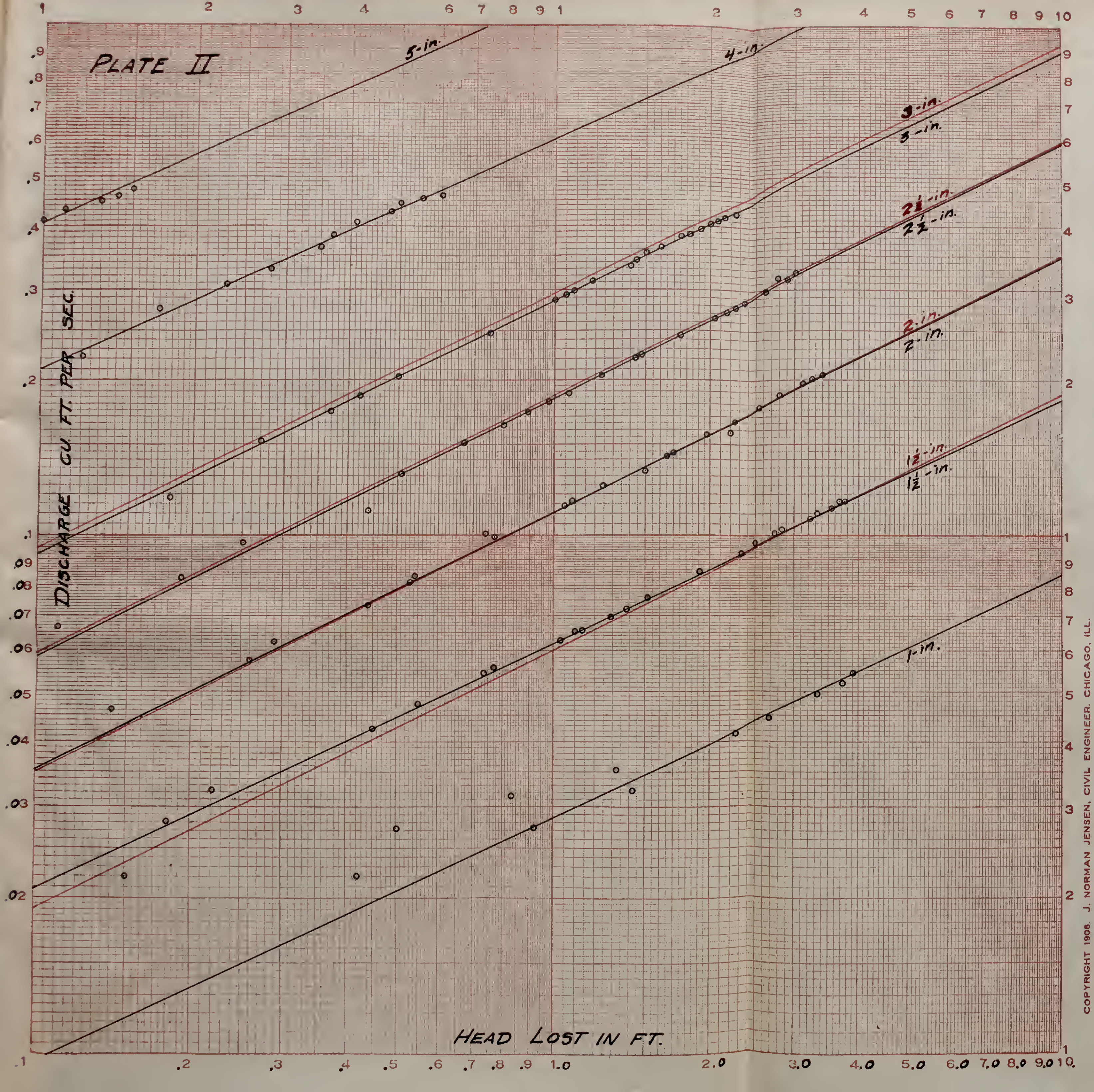
CURVES SHOWING RELATION
of
DISCHARGE
to
HEAD LOST 1-6
THROUGH ORIFICES IN 4-IN. PIPE

Black = Experimental Curves.

Red - $q = .565 \frac{F_p F_o}{F_p - F_o}\sqrt{2gh}$

PLATE II



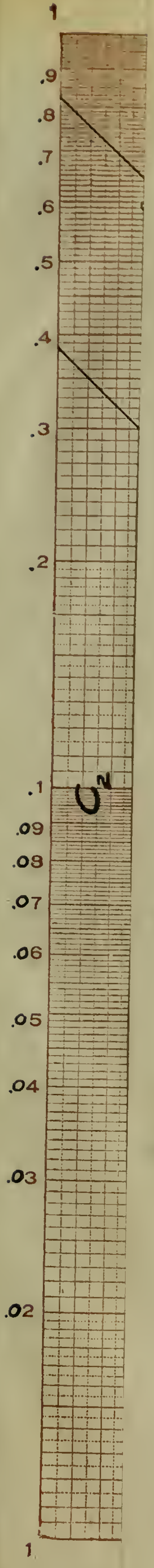


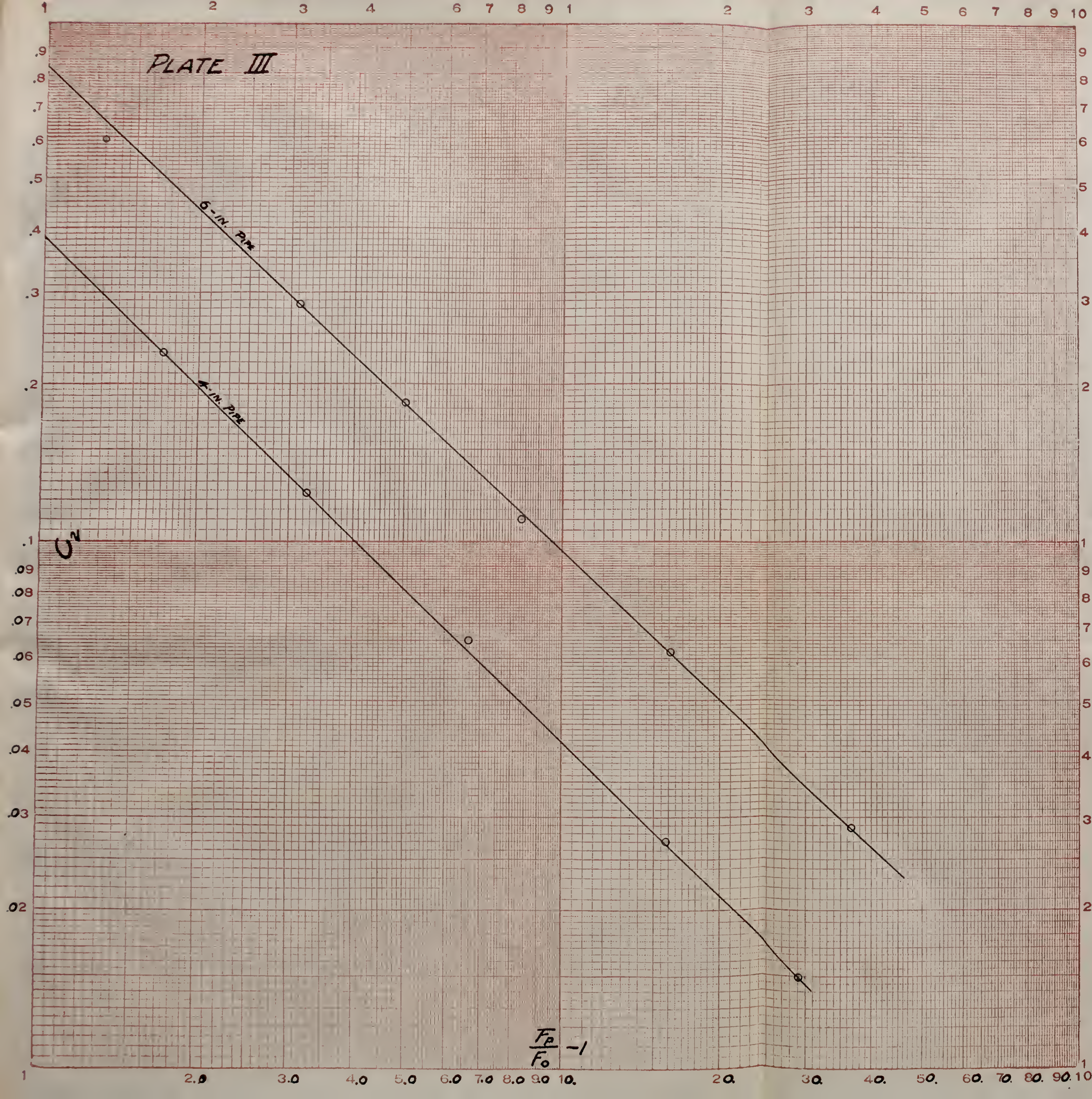
CURVES SHOWING RELATION of DISCHARGE to HEAD LOST 1-6 THROUGH ORIFICES IN 6-IN. PIPE

Black = Experimental Curves

Red = $q = .565 \frac{F_o F_p}{F_p - F_o} \sqrt{2gh}$

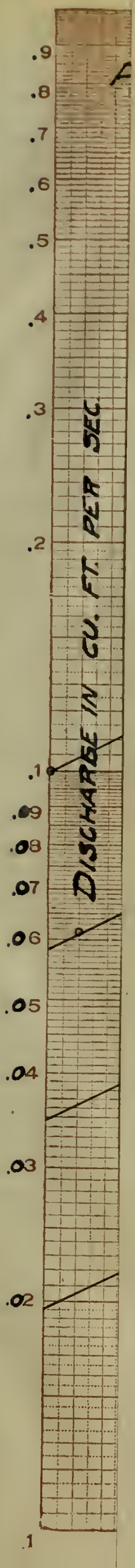
PLATE III

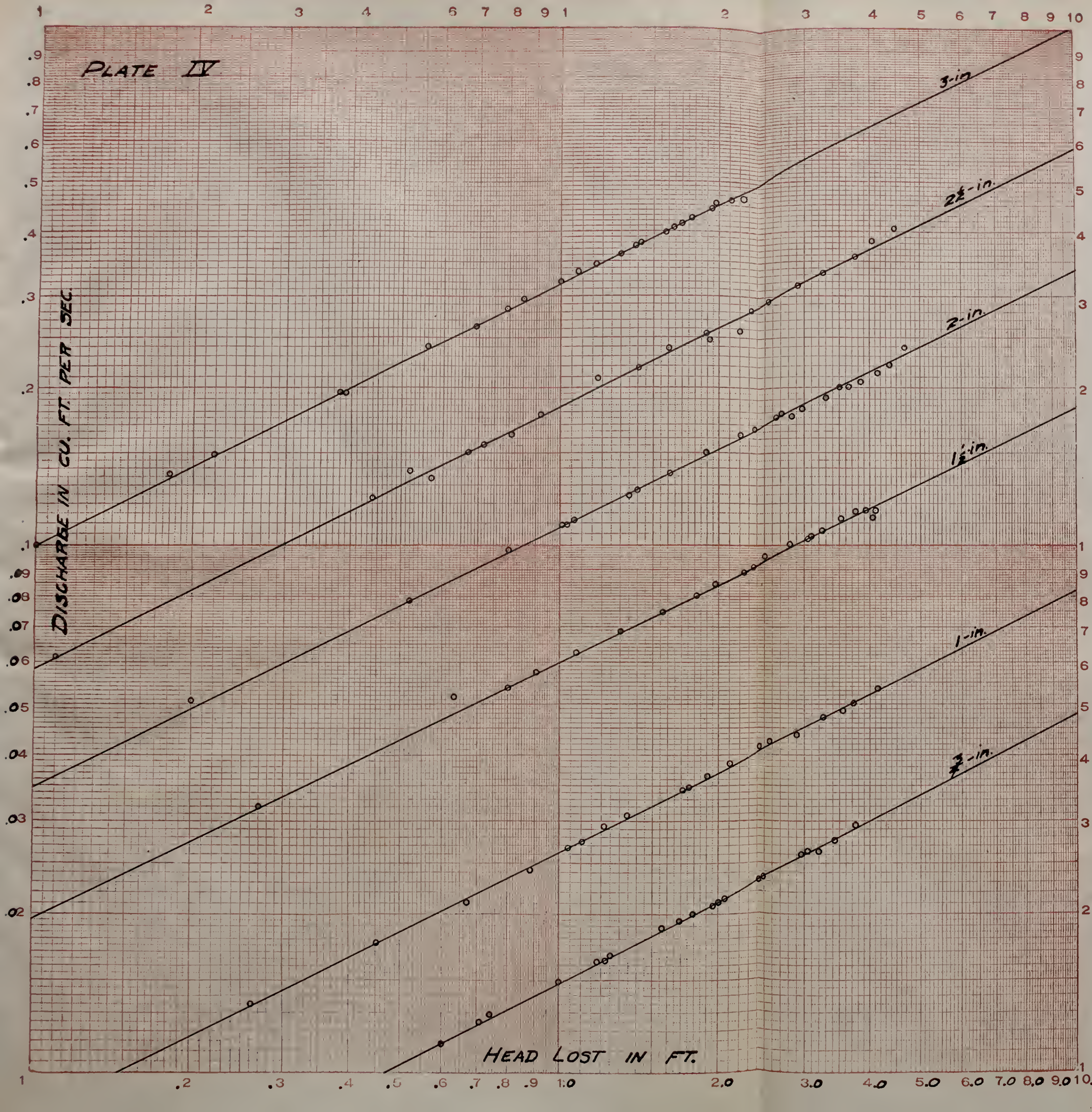




CURVES SHOWING RELATION of C_2 to $\frac{F_p}{F_o} - 1$ FOR ORIFICES IN 4-IN. AND 6-IN. PIPES

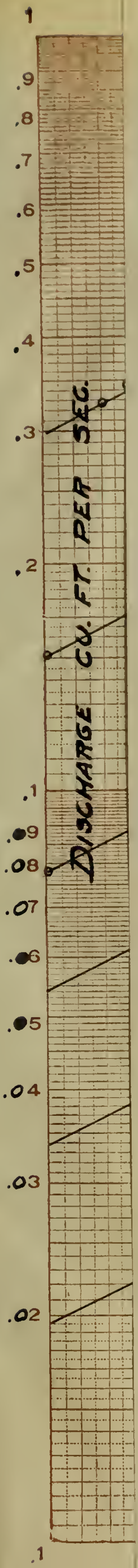
PLATE IV

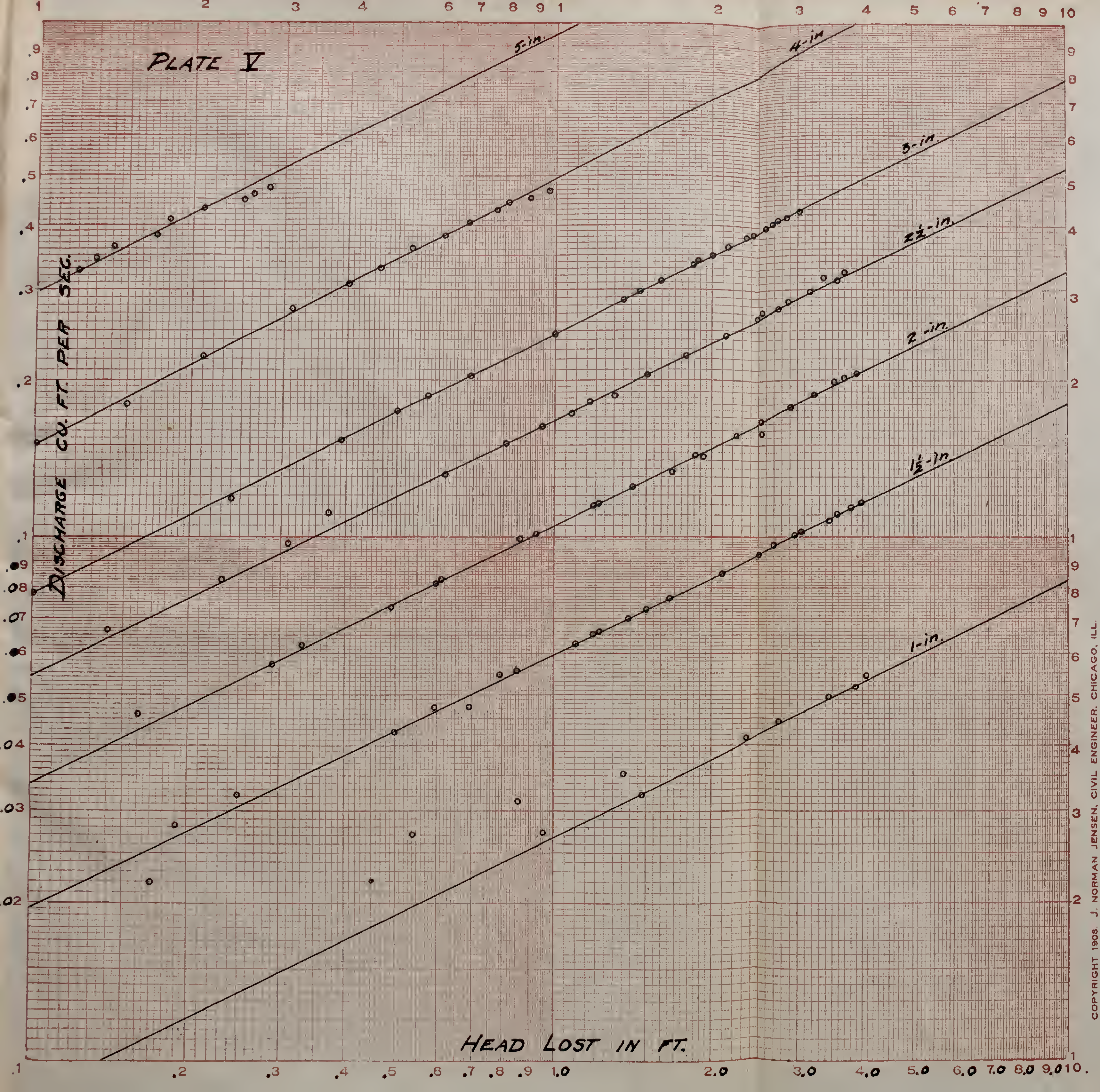




CURVES SHOWING RELATION
of
DISCHARGE
to
HEAD LOST 1-2
THROUGH ORIFICES IN 4-IN. PIPE
Black = Experimental Curves

PLATE V





CURVES SHOWING RELATION
of
DISCHARGE
to
HEAD LOST 1-2
THROUGH ORIFICES IN 6-IN. PIPE

Black = Experimental Curves